U. of Iowa 67-19

MICROBURST PHENOMENA

2. Auroral Zone Electrons*

by

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September 1967

* Work at the University of Iowa by Office of Naval Research Contract 1509(06), at the University of Calgary by National Research Council Contract NRC A-3865, and at the Southwest Center for Advanced Studies by NASA Contract NAS-r-198.

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ABSTRACT

Observations made during a high-time resolution mode of operation of the Injun 3 satellite have identified auroral zone electron microbursts, the parent phenomenon of the often observed bremsstrahlung x-ray microbursts. These electron microbursts, detected in the $E_e \geq 40$ keV (180°) (precipitating) detector and less frequently in the $E_e \geq 40$ keV (90°) (trapped) detector, have time profiles similar to those of both the symmetric and asymmetric daughter x-ray microbursts and exhibit typical peak fluxes of J_o ($E_e \geq 40$ keV) $\sim$ 3×10^5 electrons cm^{-2} sec^{-1} $sterad^{-1}$ in the 180° detector. Statistical studies of these satellite-observed microbursts reveal their occurrence predominantly in the regions of $6 \leq L \leq 8.5$ and $4{:}30 \leq$ magnetic local time $\leq 12{:}30$. Detailed statistical distributions of microburst occurrence as functions of local time and L are presented.

INTRODUCTION

In order to augment the study of auroral zone x-ray microbursts, an investigation was carried out to determine whether satellite detectors observe any phenomena which might be connected with the microbursts observed from balloons. Auroral zone x-ray microbursts have previously been discussed in great detail (Anderson and Milton [1964]; Anderson [1965]; Oliven and Gurnett [1967a]; and Venkatesan et al. [1967]), and high-time resolution measurements of these x-ray microbursts have been carried out for several years. The Injun 3 satellite provided a good opportunity to determine whether the causative precipitating particles which must result in the production of x-ray bremsstrahlung microbursts could be observed above the x-ray production layer. Consequently, data from charged particle detectors aboard the Injun 3 satellite were examined in detail for the period, January-October 1963. Although this satellite was not in operation as late as August 1965, the time at which the balloon observations of microbursts were made (Venkatesan et al. [1967]), it nevertheless provides useful information in the investigation of fast temporal changes in particle precipitation phenomena because of its incorporation of high-time resolution detectors. The Injun 4 satellite, magnetically oriented as Injun 3 and containing similar detectors, and in orbit during the period of the aforementioned balloon observations, was incapable of resolving times of less than a second, and hence could not be utilized for the study of the fast microbursts to be discussed herein.

SATELLITE DETECTORS

Injun 3, a magnetically oriented satellite, launched on December 13, 1963, had an orbit of apogee altitude 2785 km, perigee altitude 237 km, orbital inclination 70.4°, and a period of 116 minutes. The description of the satellite, designed and built at the University of Iowa, and the on-board detectors, is given in a paper by O'Brien et al. [1964]. The detectors of particular interest are the 213 Anton Geiger counters viewing electrons with energies $E_e \geq 40$ keV, oriented at 90° (trapped particles) and 180° (precipitating particles) with respect to the magnetic field, in the northern hemisphere, and having fields of view and geometric factors of 26° diameter and (0.6×10^{-2}) cm^2 ster, and 86° diameter and (5×10^{-2}) cm^2 ster, respectively (O'Brien et al. [1964]).

Of the several modes of operation available in Injun 3 (only one such mode may operate for any epoch of observations) only two were capable of resolving times of less than one second, which is a necessary requisite in the identification of microbursts. These were modes 1 and 4, which provide detector readings for both the 90° and 180° detectors, every 1/4 second and 1/16 second, respectively. Most of the data for the lifetime of the satellite were obtained in mode 1, with only nine passes (each pass of typical duration ~ 10 minutes) available employing mode 4 operation.

THE IDENTIFICATION OF ELECTRON MICROBURSTS

All nine passes available in the mode 4 operation of the satellite were examined in detail. It was found that only two passes, occurring respectively on January 17 and January 24, 1963 contained extended periods of fast fluctuations in both the 90° and 180° $E_e \geq 40$ keV detectors. The pass on January 24 contained fluctuations with time scales of the order of several seconds, examples of this type of variations having been given in Figure 6 of O'Brien's paper [1964]. In addition, faster variations (< 1 second) were also seen in fewer number. The pass of January 17 revealed a large number of examples of variations of < 1 second, and several typical cases of this type of fluctuation are presented in Figure 1. It can be seen that there are isolated bursts, as well as many occurring in trains (or in the terminology of Anderson and Milton, [1964] combs) present in these data. Visually, these events have many of the same characteristics as the balloon-observed bremsstrahlung x-ray microbursts (both symmetric and asymmetric) as discussed by Anderson and Milton [1964], Edwards et al. [1966], Venkatesan et al. [1967], Oliven and Gurnett [1967a], and several other groups. Peak fluxes of the order of

$J\ (E_e \geq 40\ \text{keV}) \sim 3 \times 10^5$ particles $cm^{-2}\ sec^{-1}\ ster^{-1}$ above the background levels for the 180° detector were commonly encountered for this type of event.

The fast time fluctuations were seen either by the 180° detector, alone, or by both the 180° and the 90° detectors. On no occasion was a fast fluctuation observed in the 90° detector, alone. The absolute change in particle flux observed by the 90° detector was typically comparable, or somewhat less (by a factor of ~ 2) than that observed by the 180° detector. The background flux upon which the fast changes were superposed was typically considerably greater in the case of the 90° (trapped) detector than in the case of the 180° (precipitating) detector, an order of magnitude difference being commonly observed (Parthasarathy, et al. [1966]). Consequently, the statistical fluctuations in the background rate of the 90° detector were ≈ 3 times those in the 180° rate, and thus, on many occasions the microbursts in the 90° detector would be masked by the large statistical fluctuations in the counting rate.

The obvious question arises as to whether the fast fluctuations observed by Injun 3 were due to temporal, or spatial characteristics of the electron precipitation phenomenon. The satellite was moving with a velocity of approximately 0.5 km per 1/16 second, and consequently localized electron precipitation of a spatial scale of approximately 4 km might masquerade in the data as "microbursts". The evidence against such an explanation is as follows:

1. To explain the fast rise, and slow fall times of many of the electron flux changes, the electron precipitation would have to exhibit an asymmetric distribution with respect to spatial co-ordinates; the distribution almost certainly being under geomagnetic control. In contradiction to this hypothesis is the fact that, while the satellite was moving from north to south during the January 24 precipitation event, and south to north during that of January 17, the electron fluctuations observed on both occasions exhibited a predominance of fast rise times, and slow decay times.

2. A common characteristic of the x-ray microburst phenomenon is the occurrence of "comb events" (Anderson and Milton [1964]; Venkatesan et al. [1967]) containing many individual microbursts.

Since a balloon detector is stationary, and integrates over a large spatial extent (~ 100 km scale size) at the bremsstrahlung production level, these observations imply the existence of repetitive temporal fluctuations in electron precipitation. The spatial extent of these electron precipitation events has been shown to be $\gtrsim 80$ km (Parks, [1967]), consequently, a satellite such as Injun 3 would have to observe "comb events" lasting of order 10 seconds before leaving the region of electron precipitation. Figure 2 presents "comb events" seen by Injun 3. Combs observed by balloon-borne detectors bear a striking similarity of duration and repetition characteristics (e.g., Anderson [1965]) to these satellite observed combs. During the period of time in question, Injun 3 travelled ~ 25 km, hence the simplest hypothesis, by far, is that Injun 3 was observing temporal fluctuations as seen commonly by balloon-borne equipment. An explanation of Figure 2 in terms of a multi-sheet spatial structure could be advanced; however, it would require a number of drastic ad hoc assumptions to explain the similarity to the known temporal variations observed previously.

3. Paper 1 (Venkatesan et al. [1967]) has shown that peak photon fluxes of ~ 20 photons cm^{-2} sec^{-1} for $h\nu > 60$ keV are commonly observed by balloon-borne detectors. An electron

precipitation of order 3-5 x 10^5 electrons cm^{-2} sec^{-1} $sterad^{-1}$ is required to produce such photon fluxes. Typical short time-scale counting rate fluctuations ($\approx$ 0.5 sec) observed by Injun 3 imply peak electron fluxes of $\gtrsim 3 \times 10^5$ electrons cm^{-2} sec^{-1} $ster^{-1}$ for $E_e \geq 40$ keV in the 180° detector (precipitating). Short time-scale fluctuations having peak fluxes up to $\sim 4 \times 10^6$ electrons cm^{-2} sec^{-1} $ster^{-1}$ (near detector saturation) are observed, but in fewer number.

On the basis of the foregoing points, we conclude that the temporal fluctuations of time scale $\approx$ 0.5 seconds commonly observed by Injun 3 are due to temporal changes in electron precipitation such as inferred previously from balloon-borne observations. We shall therefore refer to these fluctuations as "electron microbursts".

A typical asymmetric burst observed by the satellite was studied in an attempt to compare it with the balloon observations. Counting rates for average samples of both asymmetric and symmetric x-ray microbursts were integrated over 60 millisecond periods. In the case of the asymmetric burst this was performed using the approximate representation for the asymmetric burst of

$\int_{t_o}^{t_1} (1 - e^{-t/30})e^{-t/200}\, dt$, with t in milliseconds. These integrations, equivalent to the 1/16 second accumulation time of the satellite detectors, were begun at $t_o = 0, -10, -20, \ldots$ and -50 milliseconds in order to explore the consequences of non-synchronous sampling of the electron pulse by the satellite detector. The most advantageous fit of these six sets of both symmetric and asymmetric x-ray pulses to an asymmetric electron pulse observed by Injun 3 is presented in Figure 3. The asymmetric x-ray microburst measurement is seen to be in good agreement with the asymmetric electron burst viewed by the satellite, and therefore shows that asymmetric electron microbursts seen by the satellite correspond, in form, to the asymmetric bursts seen by Venkatesan, et al. [1967] and cannot be accounted for by the sampling of a symmetric burst. A similar analysis of symmetric bursts viewed by both satellite and balloons likewise exhibit excellent agreement. We, therefore, conclude that both the symmetric microburst (as seen by us and Anderson and Milton, [1964]), and the asymmetric microburst (Edwards, et al. [1966], and Venkatesan, et al. [1967]) were observed by the Injun 3 satellite, and represent variants of the one microburst phenomenon.

STATISTICAL STUDY OF OCCURRENCE

Activity similar to that present in mode 4 can be found in mode 1, in which detectors sample for 1/4 second and detector readings are given at 1/4 second intervals. Most of the data from the entire lifetime of the satellite were accumulated in this mode of operation. Depending upon the relative phasing of the electron precipitation event, and the sampling periods of the satellite, the microbursts will appear in mode 1 either as an observed maximum value and one or two points marking the decay, or as a variety of forms in which one point indicates the leading edge, one point the maximum, and one or two points the decay phase. In all cases an individual burst rising out of the background contains no more than three to four defining points (1/4 second points). Several such examples are shown in Figures 4 and 5.

A statistical study was undertaken to investigate the frequency of occurrence and any possible regional restrictions upon the appearance of these microburst events. At first, fifty random samples of data from satellite passes of various L values and local times were investigated. It became apparent that most of the electron microbursts and groups of bursts were occurring during the local hours from 04:30 - 12:30 magnetic local time and L values from 6.0 to 8.5, the same regions in which balloon-observed x-ray microbursts most commonly appear.

Subsequently, detector data from the entire lifetime of the satellite were utilized to investigate the occurrence of electron microbursts. Passes covering all 24 hours in magnetic local time and L values from 2-11 were investigated. All samples were chosen to be 8 seconds in length. Thus, for example, a pass which remained within a given local time and L range for 16 seconds was considered to be two samples each 8 seconds in length. For every L-magnetic local time combination (there being a total of 10 x 24, or 240 combinations) at least 10 such 8-second samples were investigated for the presence of microbursts. Whenever possible, 10 different passes were used for each L value - magnetic local time combination. In only a few of the higher L regions was this requirement of 10 samples not met.

Particular care was taken to assure that these variations were indeed physical phenomena rather than noise data or bit errors in the telemetry transmission. Some of the procedures followed have been previously described (Appendix 3, O'Brien [1964]).

In addition, all changes in the flux which were represented by only one isolated 1/4 second sample above the background level were not considered to be sufficient to indicate the presence of microbursts. All counting rate increments of $\leq 2\sqrt{N}$ of the background counting level were automatically rejected. In most cases, samples which contained identifiable microbursts had many such "subliminal" events. Additionally, flux changes which were classed as microbursts seldom occurred alone within an 8-second sample. Only about 11% of the total 8-second samples identified as containing any microbursts contained ≤ 3 single identifiable events. Many of these sections of data were simultaneously received by two separated tracking stations, again confirming that these microbursts were indeed true occurrences. It should be noted that by imposing these strict selection criteria upon the identification of electron microbursts, it is quite possible that some genuine events have been rejected. Thus, the statistics which follow only represent events which clearly qualify as microbursts. The percentages of microbursts occurrence would undoubtably be higher than those stated if one were to employ less restrictive selection criteria.

More than 2400 samples were investigated to determine the possible presence of microbursts. This study revealed that electron microbursts occur almost exclusively in the regions of

$6 \lesssim L \lesssim 8.5$ (corresponding to $66° \lesssim$ invariant latitude $\lesssim 70°$) and magnetic local times of 4:30 $\lesssim$ magnetic local time $\lesssim$ 12:30, with far fewer cases occurring in surrounding regions. These results are summarized in Table 1 and Figure 6. It can be seen that there are several notable exceptions to this rule, namely, the rare occurrence of microbursts in the local night hours within the 6 - 8.5 region of L. These are rare events and represent the exception rather than the rule.

The region of largest occurrence frequency of electron microbursts was further investigated to determine whether any significant pattern of precipitation could be found within this region. Sample blocks were decreased in size to encompass a region of one hour (magnetic local time) by one-half L. The samples investigated were all taken to be 8 seconds in length, and each pass was permitted to contribute only one such sample to each magnetic local time - L combination. Data from the entire lifetime of the satellite were employed. These results, as seen in Figure 7, display no distinctive pattern of activity within the region of interest.

An investigation into the possible dependence of electron microburst occurrence upon magnetic activity (as represented in large K_p values) revealed no clear correlation. Within the region of maximum occurrence as stated above, there appears to be no dependence of percentage occurrence upon the K_p value. Only a very slight dependence upon K_p outside this region in the surrounding times and L values is found. The tendency for higher percentage occurrence in these regions during periods of high K_p (> 3) is noticeable, but because of the small occurrences in these regions and hence the small total number of such microbursts, the statistics are inadequate to establish such a dependence. In addition, a study revealed that there was no significant dependence of electron microburst occurrence upon satellite altitude.

SUMMARY AND CONCLUSIONS

The identification of electron microbursts, the parent electron precipitation phenomenon responsible for the production of bremsstrahlung x-ray microbursts, has been herein established.

The characteristic times of these electron microbursts, as seen in the $E_e \geq 40$ keV geiger tube were about 1/4 second at half intensity points. Both symmetric and asymmetric (fast rise time, slower decay time) time profiles were observed. Many electron microbursts appeared in trains, or combs, as do the daughter x-ray microbursts. No characteristic periodicity has been found, to date, between these separate electron microbursts.

Typical peak fluxes above background of J ($E_e \geq 40$ keV) $\sim 3 \times 10^5$ particles cm^{-2} sec^{-1} $sterad^{-1}$ for the 180° detector were commonly encountered for these microbursts. Typical x-ray microbursts observed at balloon altitude have peak fluxes of ~ 20 counts cm^{-2} sec^{-1} for $E_{x\text{-}ray} > 60$ keV. The electron flux necessary to produce this flux of x-rays corresponds well with the aforestated satellite measurements.

The region of occurrence of electron microbursts is found to be in good agreement with the regions in which x-ray microbursts most commonly occur. This region has been established as $6 \leq L \leq 8.5$ and 4:30 ≤ magnetic local time ≤ 12:30, from more than 2400 cases studied in 240 L, magnetic local time blocks. Significant microburst activity is observed to extend to earlier local times, viz, ~ 0200 local time.

The third paper, (Oliven and Gurnett [1967b]) will explore a connection found to exist between these electron microbursts and the VLF phenomenon known as chorus. It is this connection between the auroral zone electron microbursts herein reported, their resultant auroral zone x-ray bremsstrahlung microbursts, and the VLF chorus which promises to give us the greatest insight yet into the plasma instabilities, acceleration mechanisms, and regions of occurrence of these instabilities in the magnetosphere.

ACKNOWLEDGEMENTS

The authors wish to express their thanks for the advice and support offered in this project by Professor J. A. Van Allen of the University of Iowa. This work was supported at the University of Iowa by Office of Naval Research Contract 1509(06), at the University of Calgary by National Research Council Contract NRC A-3865, and at the Southwest Center for Advanced Studies by NASA Contract NAS-r-198.

Table 1

Occurrence in L and Magnetic Local Time of Satellite Observed Microbursts Seen in 180° Detector Only and in Both 90° and 180° Detectors of Injun 3

(in percent of the total number of 8-second samples studied for the specific L and Magnetic Local Time; unless otherwise indicated at least ten 8-second samples considered for each L-Magnetic Local Time combination)

Magnetic Local Time	L Value 2	3	4	5	6	7	8	9	10	11
00	0	0	0	10B	0	0	0	0	0	0
01	0	0	0	10B	0	0	0	0	0	0
02	0	0	0	10A	10A	10A	0	0	0	10B
03	0	0	0	0	0	25A	12A	10A	0	0
04	0	0	0	0	19C	38C	22C	30A	0	0
05	0	0	0	20C	15C	26C	24C	0	30C	10B
06	0	0	0	0	28C	32C	39C	20A	10B	0
07	0	0	0	10A	43C	50C	41C	10A	0	10A
08	0	0	0	13B	30C	36C	37C	10A	10A	20Aα
09	0	0	0	19C	29C	28C	36C	20C	20A	0
10	0	0	0	31C	50C	39C	32C	0	10A	20Cα
11	0	0	0	0	38C	18C	50C	30C	20A	10A
12	0	0	0	0	0	44C	30A	0	0	0
13	0	0	0	0	8A	8B	8A	0	10A	0
14	0	0	0	0	0	0	0	10A	0	0α
15	0	0	0	0	0	0	0	0α	0α	0α
16	0	0	0	0	0	0	0	0	0α	0α
17	0	0	0	0	0	0	0	0	0	0α
18	0	0	0	0	0	0	0	0	0	0α
19	0	0	0	0	0	10A	0	0α	0α	0α
20	0	0	0	0	0	0	10A	0α	0α	0α
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	10A	10A	10C	0	0	0
23	0	0	0	0	0	0	0	0	0	0

A = seen only in 180° detector.
B = seen by both 90° and 180° detector.
C = both A and B occur within the 8-second interval.
α = less than 10 samples available.

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FIGURE CAPTIONS

Figure 1 Typical appearance of electron microbursts in the Injun 3 electron ($E_e \geq 40$ keV) detectors at sixteen samples per second.

Figure 2 Trains or combs of electron microbursts seen by Injun 3 with similar features as those seen in balloon x-ray detectors of Venkatesan, et al. [1967] and Anderson [1965].

Figure 3 Comparison of the most advantageous fit of balloon x-ray data of Venkatesan, et al. [1967] with a sample of a satellite asymmetric microburst. The asymmetric satellite burst is compared with an asymmetric x-ray burst and a symmetric x-ray burst. X-ray data have been accumulated for 60 millisecond intervals. The satellite microburst is indicated in Figure 2 with an asterisk.

Figure 4 Typical microburst appearances in four samples $(\text{sec})^{-1}$ operation of the satellite detectors.

Figure 5 Typical microburst appearance in the four samples $(\text{sec})^{-1}$ operation of the satellite detector. Isolated microbursts as well as some appearing in trains (combs) can be seen.

Figure 6 The distribution of microburst occurrence in invariant latitude and magnetic local time of the satellite as observed by Injun 3. Each sample block contains at least 10 samples.

Figure 7 The occurrence in invariant latitude and magnetic local time of the electron microbursts detected by Injun 3.

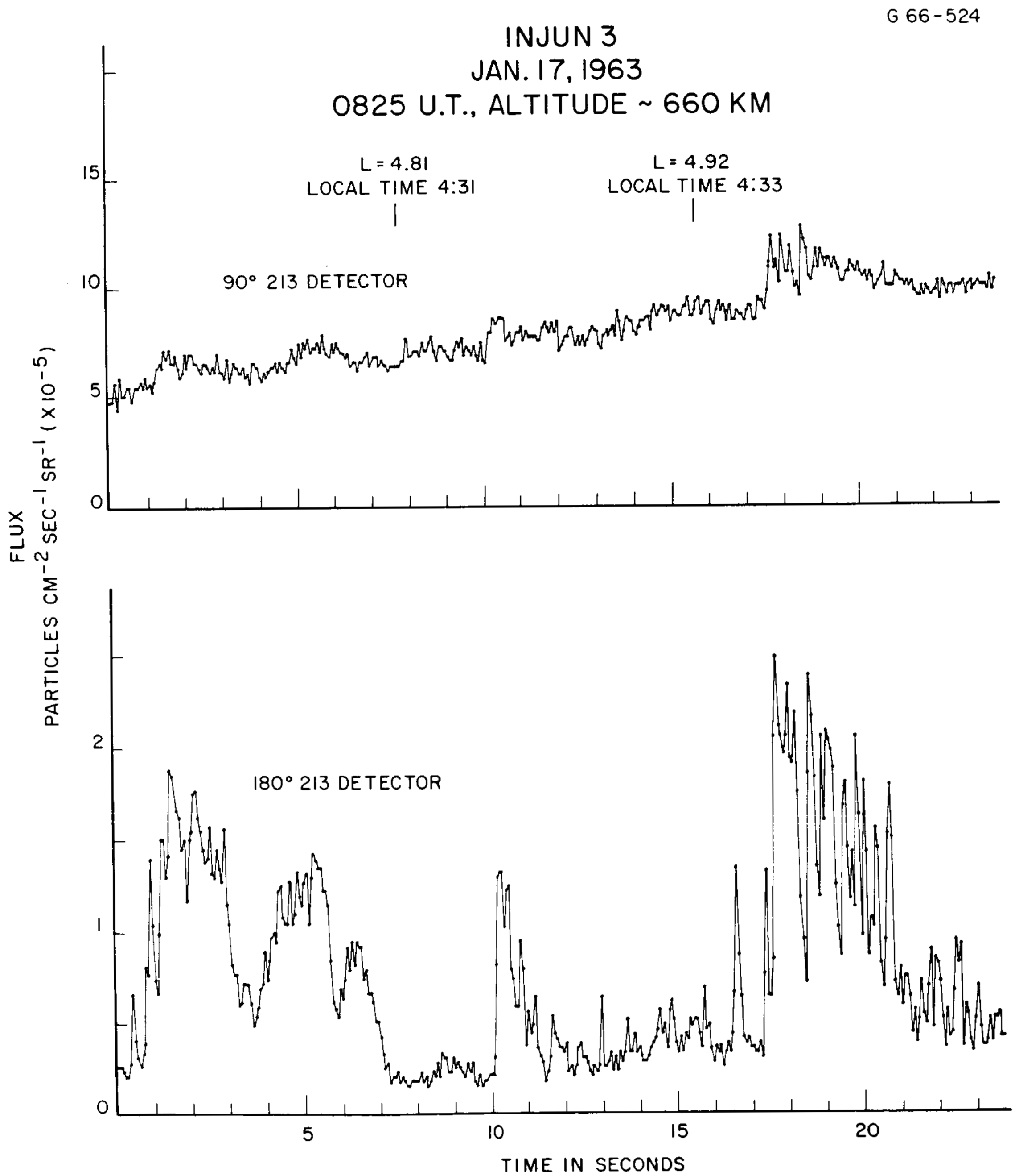
G 66-524
INJUN 3
JAN. 17, 1963
0825 U.T., ALTITUDE ~ 660 KM
L = 4.81
LOCAL TIME 4:31
L = 4.92
LOCAL TIME 4:33
90° 213 DETECTOR
180° 213 DETECTOR
FLUX
PARTICLES CM^{-2} SEC^{-1} SR^{-1} (X 10^{-5})
TIME IN SECONDS
0
5
10
15
0
1
2
5
10
15
20

FIGURE 1

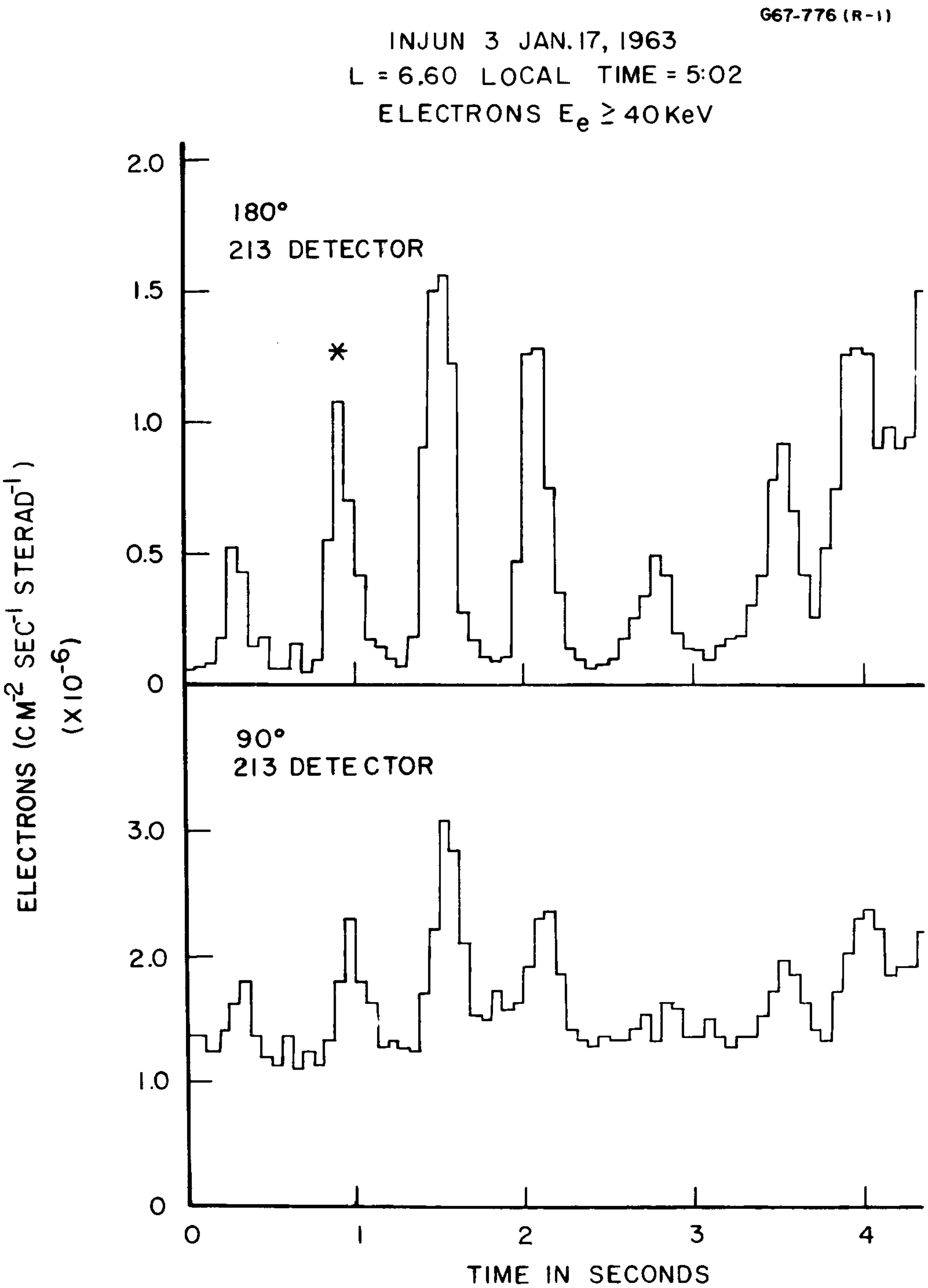
G67-776 (R-1)
INJUN 3 JAN. 17, 1963
L = 6.60 LOCAL TIME = 5:02
ELECTRONS $E_e \geq 40$ KeV
180°
213 DETECTOR
*
90°
213 DETECTOR
ELECTRONS (CM^{-2} SEC^{-1} $STERAD^{-1}$)
($\times 10^{-6}$)
2.0
1.5
1.0
0.5
0
3.0
2.0
1.0
0
0
1
2
3
4
TIME IN SECONDS

FIGURE 2

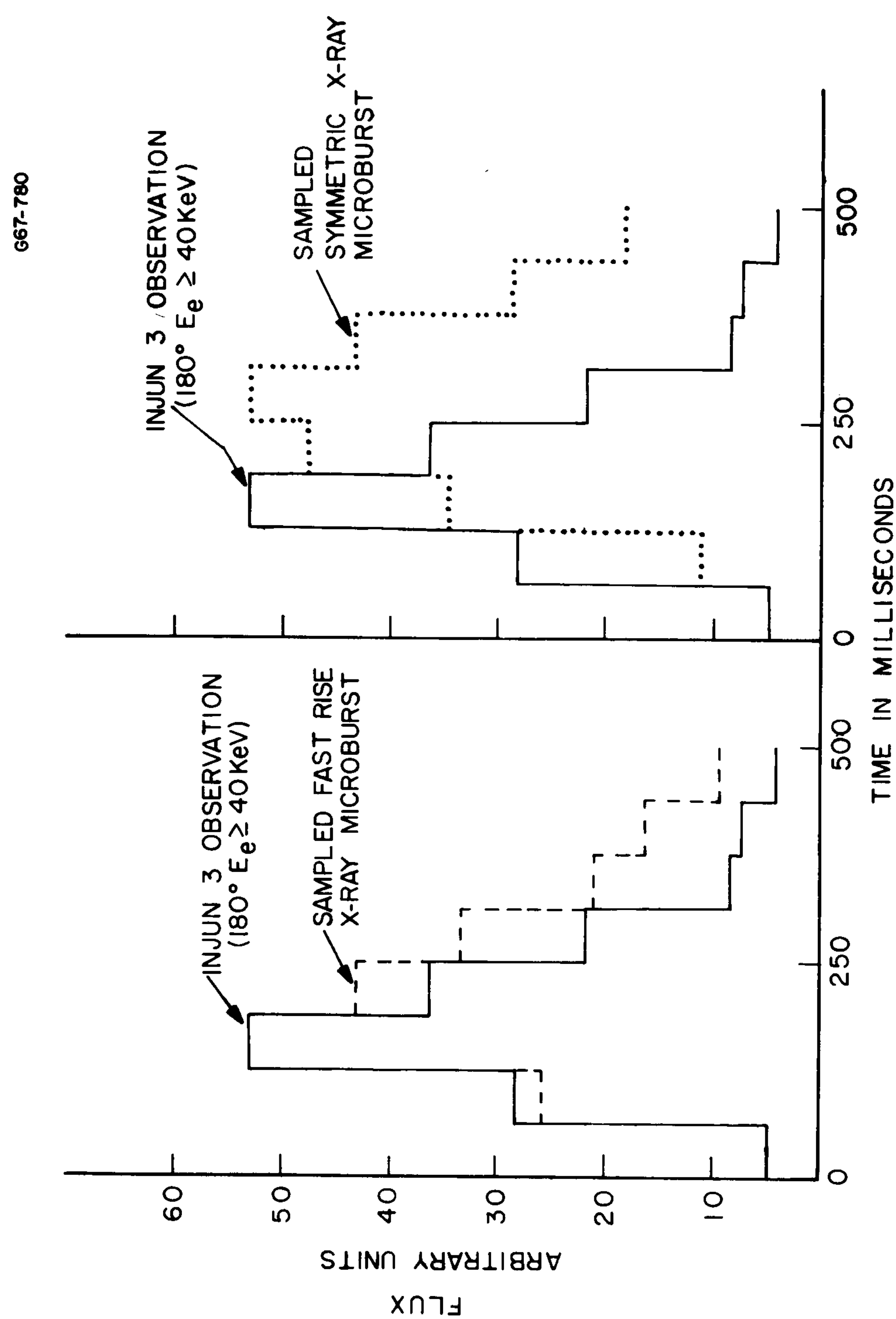
G67-780
INJUN 3 OBSERVATION
(180° Ee ≥ 40 KeV)
SAMPLED SYMMETRIC X-RAY MICROBURST
INJUN 3 OBSERVATION
(180° Ee ≥ 40 KeV)
SAMPLED FAST RISE X-RAY MICROBURST
0
250
500
0
250
500
TIME IN MILLISECONDS
60
50
40
30
20
10
FLUX
ARBITRARY UNITS

FIGURE 3

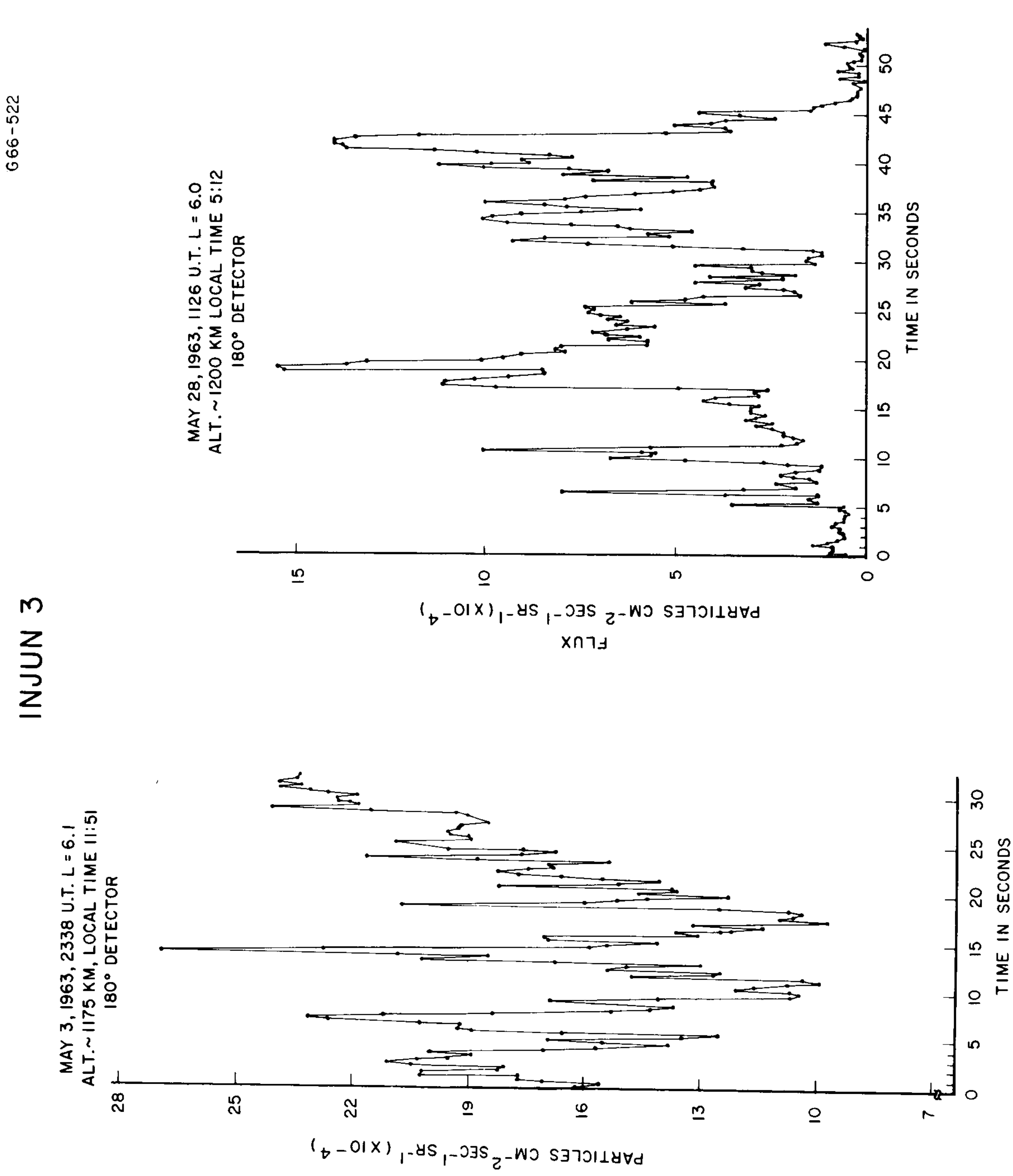
G66-522
INJUN 3
MAY 3, 1963, 2338 U.T. L = 6.1
ALT.~1175 KM, LOCAL TIME 11:51
180° DETECTOR
FLUX
PARTICLES CM^{-2}SEC^{-1}SR^{-1} (X10^{-4})
TIME IN SECONDS
MAY 28, 1963, 1126 U.T. L = 6.0
ALT.~1200 KM LOCAL TIME 5:12
180° DETECTOR
FLUX
PARTICLES CM^{-2} SEC^{-1} SR^{-1} (X10^{-4})
TIME IN SECONDS

FIGURE 4

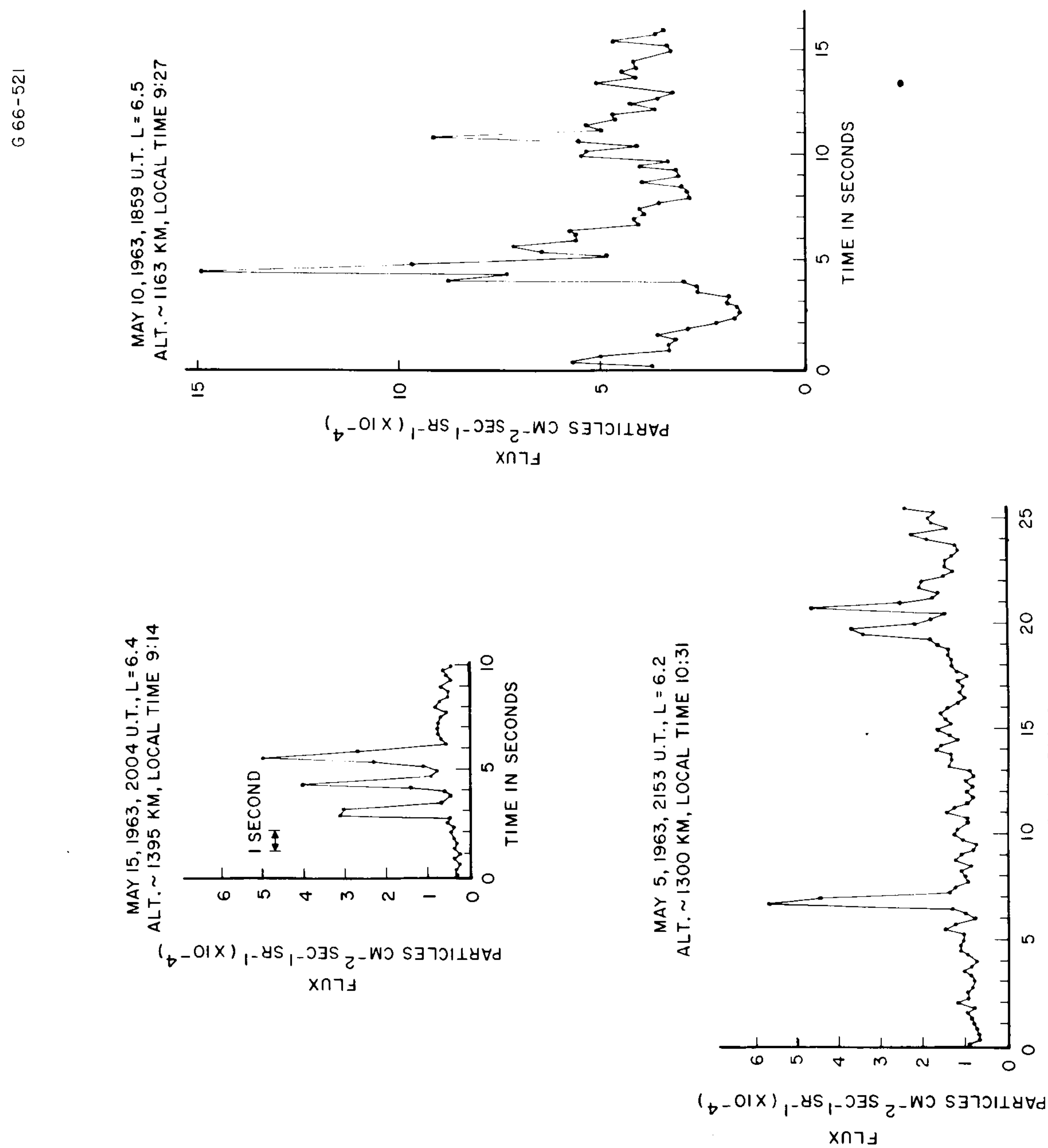
G 66-521
MAY 10, 1963, 1859 U.T. L = 6.5
ALT. ~ 1163 KM, LOCAL TIME 9:27
FLUX
PARTICLES CM-2 SEC-1 SR-1 (X 10-4)
TIME IN SECONDS
MAY 15, 1963, 2004 U.T., L = 6.4
ALT. ~ 1395 KM, LOCAL TIME 9:14
I SECOND
FLUX
PARTICLES CM-2 SEC-1 SR-1 (X 10-4)
TIME IN SECONDS
MAY 5, 1963, 2153 U.T., L = 6.2
ALT. ~ 1300 KM, LOCAL TIME 10:31
FLUX
PARTICLES CM-2 SEC-1 SR-1 (X 10-4)
TIME IN SECONDS

FIGURE 5

G 66-808

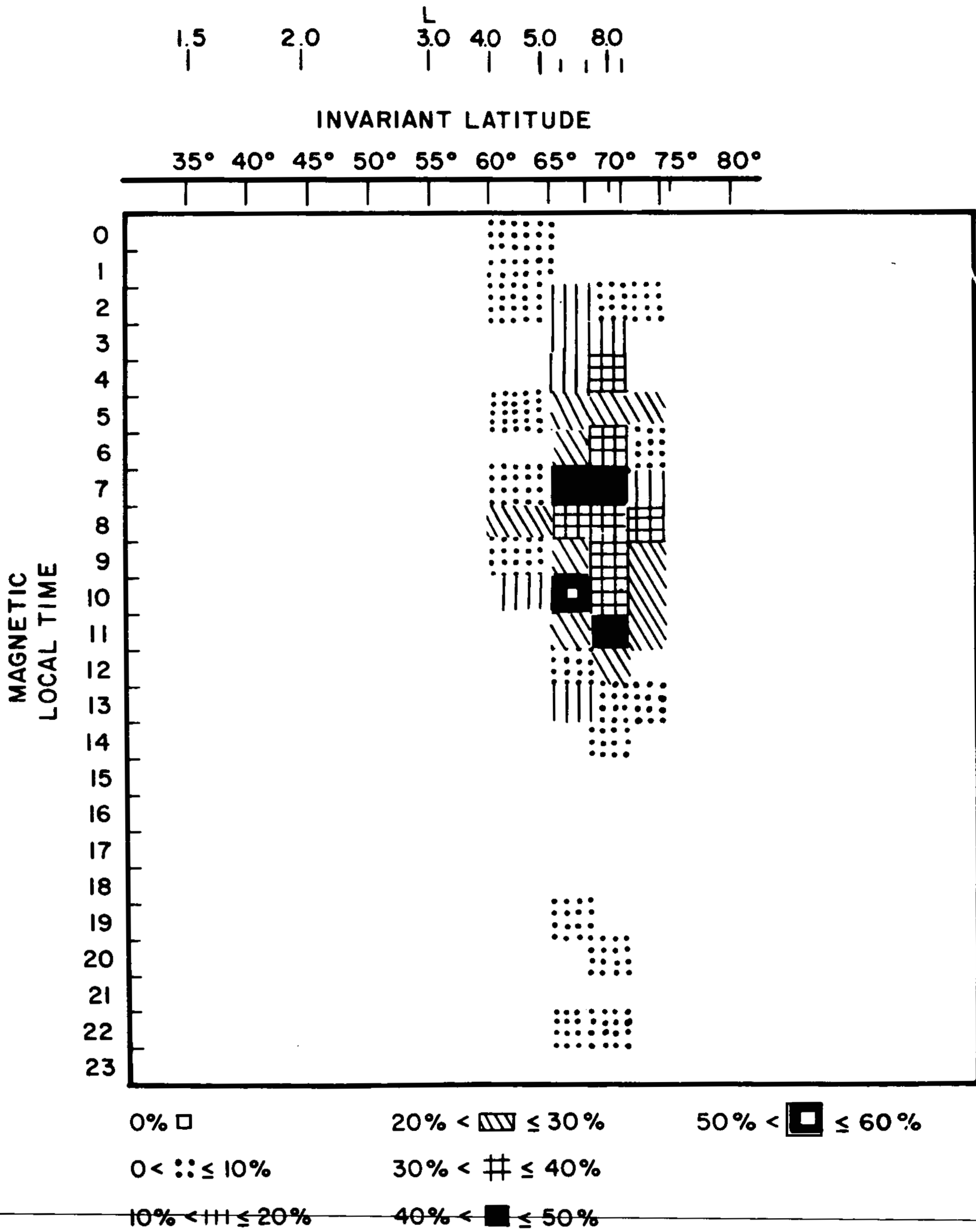

FIGURE 6

G 66-822

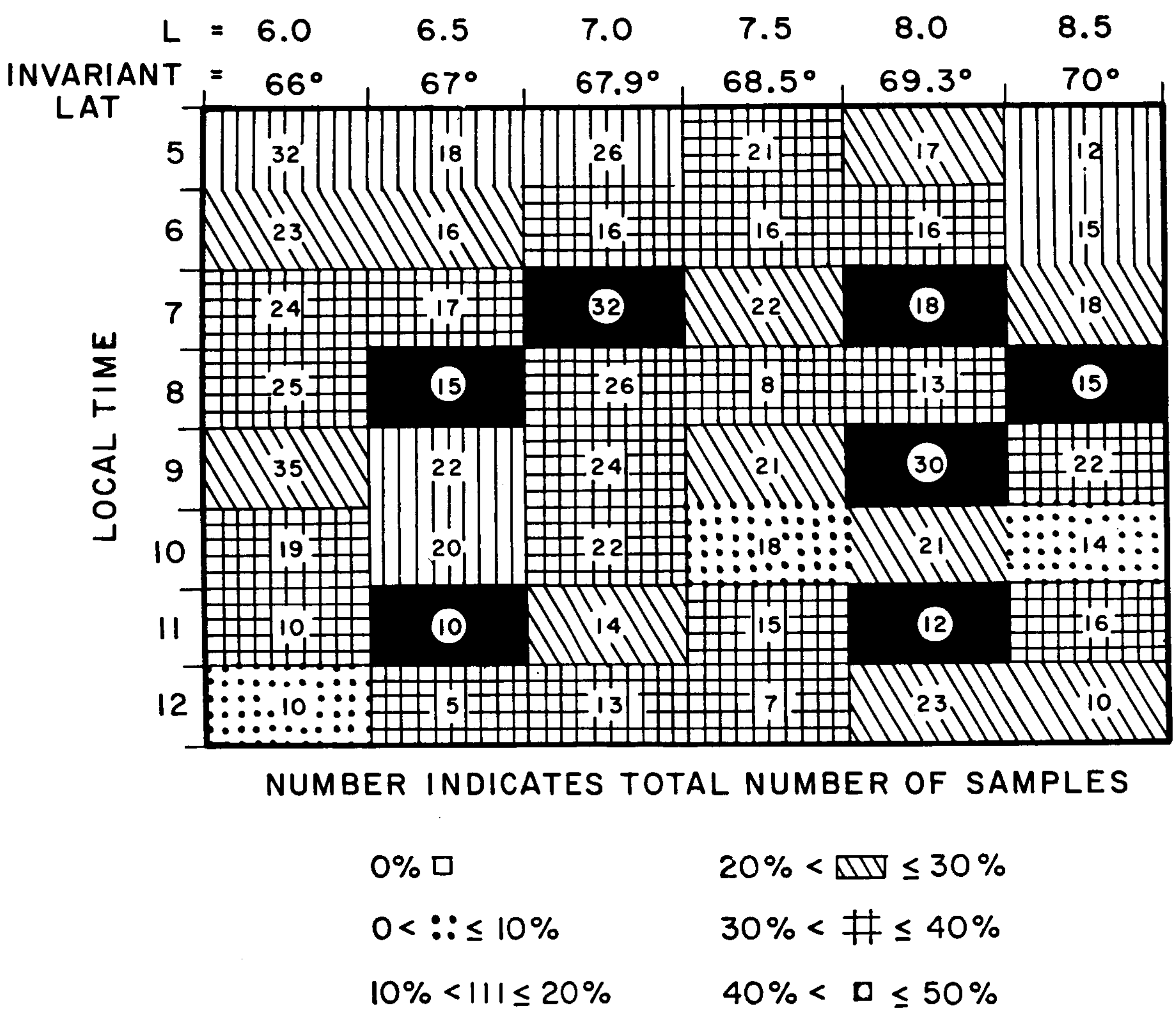

FIGURE 7

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* University of Iowa Department of Physics and Astronomy	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

Microburst Phenomena 2. Auroral Zone Electrons

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Progess August 1967

5. AUTHOR(S) *(Last name, first name, initial)*

Oliven, M. N., Venkatesan, D., McCracken, K. G.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
August 1967	31	9

8a. CONTRACT OR GRANT NO. Nonr 1509(06) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) U. of Iowa 67-19 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*

10. AVAILABILITY/LIMITATION NOTICES

Distribution of this document is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Office of Naval Research

13. ABSTRACT

(See next page)

DD FORM 1 JAN 64 1473

UNCLASSIFIED
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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Microburst Phenomena						
Microburst Phenomena 2. Auroral Zone Electrons						
Satellite Observed Auroral Zone Precipitating Electrons						
Auroral Zone Precipitation						

INSTRUCTIONS

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ABSTRACT

Observations made during a high-time resolution mode of operation of the Injun 3 satellite have identified auroral zone electron microbursts, the parent phenomenon of the often observed bremsstrahlung x-ray microbursts. These electron microbursts, detected in the $E_e \geq 40$ keV (180°) (precipitating) detector and less frequently in the $E_e \geq 40$ keV (90°)(trapped) detector, have time profiles similar to those of both the symmetric and asymmetric daughter x-ray microbursts and exhibit typical peak fluxes of J_o ($E_e \geq 40$ keV) $\sim 3 \times 10^5$ electrons cm^{-2} sec^{-1} $sterad^{-1}$ in the 180° detector. Statistical studies of these satellite-observed microbursts reveal their occurrence predominantly in the regions of $6 \leq L \leq 8.5$ and $4{:}30 \leq$ magnetic local time $\leq 12{:}30$. Detailed statistical distributions of microburst occurrence as functions of local time and L are presented.